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Basal ganglia and memory retrieval during delayed match-to-sample and non-match-to-sample tasks

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Top-down guidance of visual search requires the ability to bias the processing of visual features towards the characteristics of the desired object. Whatever form they may take, these characteristics (that we will call here a template of the object) have to be transferred from memory to the visual cortical areas, either from long-term memory or working memory. High visual areas like the inferotemporal cortex, or visuo-mnemonic areas in the medial temporal lobe have been shown to exhibit sustained activities during delayed matching-to-sample (DMS) or delayed non-matching-to-sample (DNMS) tasks, showing their involvement in working memory (WM) processes [1]. Particularly, perirhinal cortex (PRh) is involved in object recognition, novelty detection and categorization, and its impairment leads to severe deficits in DMS and DNMS tasks [2].

We designed in [3] a computational model of PRh that was able to perform multimodal categorization despite partial object presentation. Its main feature was the incorporation of dopaminergic modulation of synaptic currents, which allowed the model to exhibit sustained activities in clusters of cells representing a given object under an optimal level of tonic dopamine (DA) firing. We also observed propagation of activity within a cluster, which leads to the interesting property that the visual information contained in a cluster can be retrieved trough the stimulation of a very limited number of cells by thalamic afferents. We therefore formulated the hypothesis that PRh is potential site where visual memory can be retrieved through partial thalamic stimulation in order to bias processing in the ventral stream through feedback modulation.

Given the fact that PRh receives connections from parts of the thalamus that are tonically inhibited by basal ganglia (BG) structures [4], we here suggest that BG can act as controller for memory retrieval in PRh, but without any visual details about the object to be retrieved. We tested this hypothesis by building a computational model involving PRh, BG structures, thalamus and a prefrontal cortex (PFC) area that performs static working memory in a manner functionally similar to [5]. We applied this model to interlaced DMS and DNMS tasks, where one of two objects (A or B) is first presented to the system, followed by a task cue indicating whether the system should perform DMS or DNMS, then both A and B objects. If the system selects the correct object in PRh, it receives a probabilistic reward that elicits a phasic DA burst.

The model is composed of competing mean firing-rate neurons that interacts through connections having weights evolve through an homeostatic Hebbian learning rule. Both PRh and PFC areas project on the input structure of BG, the nucleus accumbens (NAcc), which in turn project to the globus pallidus (GPi) that tonically inhibits the thalamus. Selective inhibition of a GPi cell allows its efferent thalamic cells to exhibit activity and therefore stimulate the corresponding cluster in PRh. The DA cells slowly learn to predict reward associated to NAcc patterns associated to tasks, attenuating their response to frequently rewarded tasks, and showing depression when reward do not occur. The model is able to learn the two tasks concurrently after around 100 trials and exhibit interesting parallel search properties when the number of cells in GPi increases. This model suggests that memory retrieval can be controlled by BG which learns to activate PRh cells depending on task requirements, without information about the visual details of the objects.

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